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Patentanmeldung Nr. Patent application No. Demande de brevet n°

03075432.9

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

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Anmeldung Nr:
Application no.: 03075432.9
Demande no:

Anmeldetag:
Date of filing: 14.02.03
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Lithographic apparatus with alignment subsystem, device manufacturing method using alignment, and alignment structure

In Anspruch genommene Prioriät(en) / Priority(ies) claimed /Priorité(s) revendiquée(s)
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/
Classification internationale des brevets:

G03F/

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LU MC NL
PT SE SI SK TR LI

Lithographic apparatus with alignment subsystem, device manufacturing method using alignment, and alignment structure

The present invention relates in a first aspect to a lithographic projection apparatus comprising:

- a radiation system for providing a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate with an alignment structure thereon, the alignment structure having spatially periodic optical properties;
- a projection system for projecting the patterned beam onto a target portion of the substrate; and
- an alignment subsystem for aligning the substrate on the substrate table relative to the patterning means, the alignment subsystem comprising
  - an optical interference arrangement for optically processing light reflected from or transmitted by the alignment structure, to produce measurement light whose intensity varies with a phase of the spatially periodic alignment structure relative to a reference position defined relative to the patterning means;
  - a sensor connected to the optical interference arrangement for measuring intensity and/or phase information of the measurement light,
- an actuator for controlling a relative position of the substrate table and the patterning means based on the intensity and/or phase information of the measurement light.

Furthermore, in a second aspect, the present invention relates to a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material, the substrate comprising an alignment structure with spatially varying optical properties;
- providing a projection beam of radiation using a radiation system;

- using patterning means to endow the projection beam with a pattern in its cross-section;

- aligning the substrate relative to the patterning means, said aligning comprising:

- incorporating the substrate in an optical interference arrangement, which optically processes light reflected from or transmitted by the alignment structure, to produce measurement light of which the intensity varies with a phase of the spatially periodic alignment structure relative to a reference position defined relative to the patterning means;

- measuring intensity and/or phase information of the measurement light;

- controlling a relative position of the substrate and the patterning means based on the intensity and/or phase information; and

- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material.

In a third aspect, the present invention relates to an alignment structure for aligning a work piece relative to a reference position using interferometric measurements, the alignment structure comprising at least one phase grating mark having a plurality of adjacent lines and spaces with a predetermined periodicity.

The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the

mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired;

- A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described here above, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required; and

- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the

patterning means as here above set forth.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper or step-and-repeat apparatus. In an alternative apparatus — commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant

thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, both incorporated herein by reference.

Before a pattern can be projected onto a substrate, the substrate has to be accurately positioned relative to the patterning means, so that the pattern will be projected onto the substrate accurately at a required position. In modern semiconductor manufacturing this positioning has to be realized with nanometer accuracy.

US patent No 5,477,057 and European patent application EP-A-1148390 describe such alignment, using a phase grating alignment system. Such a system uses a substrate that includes an alignment structure with periodically variable optical properties. The phase grating alignment system measures the phase of the period of the alignment structure relative to some reference position that is defined (directly or indirectly) relative to the patterning means. From the phase, a measurement of the position of the substrate is obtained.

The phase measurement is realised by incorporating the alignment structure

in an optical interference arrangement that outputs light with an intensity that depends on the phase. The interference arrangement contains for example an imaging element that selects light diffracted by the alignment structure in a selected order of diffraction and images the selected light onto a reference structure in the lithographic apparatus. The reference structure has spatially periodically variable optical properties, with a period that corresponds to the period of the image of the alignment structure. As a result, the light output through the reference structure forms a kind of Moiré pattern. This pattern varies as the image of the alignment structure moves relative to the reference structure, dependent on the extent to which the image of the least reflective parts of the periods of the alignment structure coincide with the least transmissive parts of the periods of the reference structure. As a result the spatially averaged intensity of the output light varies periodically as a function of the position of the substrate.

A similar periodic variation can also be realised without a reference structure. European patent application No. EP 1148390 describes how interference may be used between light from the alignment structure that reaches a detector along two paths which correspond to images of the alignment structure that have been rotated 180 degrees with respect to one another. In this case, the centre of that rotation serves to provide a defined position relative to the lithographic apparatus and the detected light intensity varies periodically as a function of the position of the substrate relative to the defined position.

In such interference arrangements the periodic variation of the averaged intensity can be measured without requiring a detector with high spatial resolution. The measurement of the intensity of the detected light makes it possible to assign phase values to different positions of the alignment structure. The phase values in turn are used for accurate positioning of the substrate in the direction of periodical variation of the optical properties of the alignment structure.

Using a phase grating alignment subsystem allows a high alignment accuracy to be realised. Selection of an individual order of diffraction considerably reduces noise since only light which has the spatial frequency of the alignment structure is detected. Compared to alignment techniques that use electronic pattern recognition of images of semiconductor wafers phase grating filtering techniques realise accurate and low-noise alignment with detection and control circuits that are less critical for the alignment.

The phase grating alignment technique has the problem that it only works when sufficiently large alignment structures and/or reference structures can be used such that the substrate can be initially positioned so that the alignment structure is imaged onto the reference structure. Large alignment structures and/or reference structures are expensive, e.g. because they occupy space on the substrate which could otherwise contain circuit components. Therefore it is desirable to reduce the area of the alignment structures and/or the reference structures. However, it has been found that when an alignment structure is less than a given size the structure, although still suitable for accurate positioning purposes, will not always work immediately because the image of the alignment structure has no overlap with the reference structure when the substrate is initially positioned.

Also, the periodic alignment structure in combination with the interference arrangement will provide an output signal with a certain periodicity in it. E.g., when using a 8.0 μm phase grating as alignment structure and reference grating, the position can be accurately positioned, but only within 8.0 μm. When using a Nonius-principle measurement with an alignment structure having two different phase gratings of 8.0 and 8.8 μm, a periodicity of 88 μm exists. With the existing (fine) alignment methods, therefore, there is a chance that an error is made of one or more periods of the periodic signal. Here, periodicity is defined as the dimension of a single period of a periodic signal.

It is an object of the present invention to provide for alignment of the substrate and the patterning means in which a capture range of a periodic alignment system is provided beyond its own periodicity. Also, the object of the present invention is to provide a more robust alignment of the wafer.

This and other objects are achieved according to the invention in a lithographic apparatus as specified in the opening paragraph, characterized in that the alignment structure comprises a non-periodic feature which is detectable as a capture position or a check position using the alignment subsystem.

By including a non-periodic feature in the alignment structure, which can be detected using the normal alignment subsystem, a precise capture point for starting a fine wafer alignment can be provided by the present lithography projection apparatus. This

allows removal of the periodic error ambiguity of existing (fine) wafer alignment methods, in any case beyond the periodicity of the fine alignment method. Alternatively, the present lithographic apparatus may be used to check afterwards (i.e. after or during alignment of the wafer) whether or not a periodic error has been made. Using the present alignment subsystem embodiment a priori, the capture range of the alignment subsystem may be extended, and using the alignment subsystem a posteriori as a check will increase the robustness of the alignment subsystem.

The non-periodic feature of the alignment structure may either induce a detectable phase shift in the detected signal, or a detectable intensity shift of the detected signal. Various embodiments exist which each may provide their own specific advantages.

In one embodiment of the phase shift inducing non-periodic feature, the non-periodic feature is formed by a phase shift between two parts of the alignment structure by a change of the width of one (or more) of the lines or spaces of the alignment structure. In this case the alignment structure has two parts with the same periodicity of lines and spaces, but one (or more) of the spaces is reduced or enlarged in length to provide the non-periodic feature. One exemplary form reduces the space at the intersection of the two parts to half the periodicity of the phase grating (e.g. 4 μm in the case of a 8.0 μm phase grating) or extends it to one and half the periodicity (i.e. 12 μm for the same phase grating). Effectively, in the transition region, the contributions to the measured signal of the alignment subsystem is then exactly in opposite phase for the two parts, which allows easy detection of the capture position (i.e. the position where the phase gradient of the detected signal is maximum).

However, due to the opposite contributions, problems may arise due to the resulting low amplitude of the detected signal. This may be prevented by making the space even smaller (e.g. 200 nm in the case of a 8.0 μm phase grating), which results in a detected signal in which the phase change is still detectable, while the amplitude of the detected signal remains high.

In a further embodiment of the phase shift inducing system, the optical interference arrangement comprises a reference grating, the non-periodic feature comprises a transition from a first part to a second part of the alignment structure with a first and

second periodicity, respectively, which first and second periodicity are below, respectively greater than the periodicity of the reference grating, and the alignment subsystem is arranged to detect the capture position or check position from the resulting sloped phase information of the measurement light. Here, again, periodicity is the dimension of a single period in a periodical system, i.e. the dimension of a combination of a line and a space (greater periodicity thus means that the distance between two consecutive lines is larger). By properly selecting the periods of the first and second part of the alignment structure with respect to the reference phase grating, the phase of the detected signal will change linearly with varying mutual displacement, but with opposite sign for the first part and second part. The capture position or check position can then be derived from the intersection of the two sloped phase signals.

The resulting phase of the detected signal may in a further embodiment have the form of a sinusoidal shape, which allows an easy detection of the capture position, e.g. using a sinus profile fitting of the detected phase signal. For this, the alignment structure comprises a position dependent period change according to

$$\Delta(x)=\frac{\cos\left(\frac{2\pi}{L}x\right)-1}{x}$$

in which $\Delta(x)$ is the position dependent period change, x is the position along the alignment structure and L is the length of the alignment structure over which the phase should vary, and the alignment subsystem is arranged to detect the capture position or check position from the resulting sinusoidal shaped phase information of the measurement light.

Advantageously, the sinusoidal phase profile mark is designed such that the resulting sinus curve of the phase of the detected signal has a period which is much larger than the periodicity of the fine alignment method (e.g. greater than 88 μm).

For the second class of marks, in which the intensity of the detected alignment signal is used to determine the capture position or check position, a first embodiment utilizes the finite dimension of the alignment structure as a non-periodic feature. In this case, the alignment subsystem is arranged to detect the capture position from the envelope of the intensity of the measurement light. In general, alignment

structures in phase grating alignment systems are longer than they are wide, and the fine wafer alignment is executed using a scan of the alignment structure along its longest direction. To find a capture position for the coarse wafer alignment, the envelope of the detected alignment signal corresponds with the dimensions of the alignment structure used, and thus allows a capture position to be found.

In a further embodiment, the alignment structure has a first dimension in a first direction and a second dimension in a second direction, in which the second direction is substantially perpendicular to the first, in which the non-periodic feature is the first and/or second dimension of the alignment structure. This first and/or second dimension may be detected using a scan of the alignment mark at an angle α between 0° and 90° with the first direction.

This embodiment may be used for all kinds of alignment structures, and is also called diagonal scan. When the scan is performed at an angle α to the first direction, the capture position in the second direction may be found. In general, alignment is performed in both the first and second direction, using mutually perpendicular alignment structures. So when scanning a first alignment mark (extending in the first direction) a capture position may be derived for the second alignment mark (extending in the second direction) and vice versa.

In a further embodiment, the diagonal scan is performed at an angle α larger than 0°, more preferably at an angle α larger than 10°, e.g. at an angle α of 45°.

This embodiment may also be used when two alignment structures are present on the wafer for the alignment subsystem (e.g. a 8.0 μm and a 8.8 μm phase grating). After a diagonal scan is performed at an angle α to the first direction for the first alignment structure, the scanning is repeated for the second alignment structure, but now at an angle $-\alpha$ to the first direction. This will provide a capture position with a higher confidence (more robust solution).

For α=0°, the scanning is performed along the first direction only. Due to the finite dimension of the alignment structure, also in the first direction, this provides a capture position in the first direction.

For α=90°, the scanning is performed along the second direction of the

alignment structure. As the dimension of the alignment structure in the second direction is precisely known, this allows to determine a capture position in the second direction, which may be used when performing fine alignment using a second alignment structure. In this case, it is possible that the reference grating and the alignment structure are precisely aligned, so that a very small resulting signal is detected. This may be prevented by using a reference grating with a periodicity different from the alignment structure, or by performing a new scan at a slightly offset starting position.

In a still further embodiment, the non-periodic feature is formed by the transition from a first part of the alignment structure to a second part of the alignment structure, the first part having a periodicity of X μm and the second part having a periodicity of X/n μm, n being an integer number. The alignment subsystem is arranged to detect the capture position or check position from a change in the intensity of an n-th order of diffraction of the measurement light. Two part alignment structures are relatively easy to produce, especially when choosing the parameters correctly. Care must be taken that the shift in intensity of the detected alignment signal is large enough to be detected reliably, but also that the lower signal still has a sufficiently high amplitude. The invention could be implemented using a combination of a 8.0 μm part and a 8.0/7 μm part. Also the combination of X=8.0 μm and n=5 (grating period of 8.0 and 1.6 μm, resp.) may be implemented, as well as other suitable combinations.

In an alternative embodiment of the two part alignment structure, the non-periodic feature is formed by the transition from a first part of the alignment structure to a second part of the alignment structure, the first part having a first duty cycle value of the lines and spaces and the second part having a second duty cycle value of the lines and spaces, and the alignment subsystem is arranged to detect the capture position or check position from a change in the intensity of the measurement light. Duty cycle is the ratio of the width of a line and a space in the alignment structure. As a different duty cycle of a phase grating in combination with the optical interference arrangement will result in a different amplitude of the detected signal, this allows to detect the capture position

According to the second aspect of the invention there is provided a device manufacturing method as defined in the opening paragraph above, in which the alignment

structure comprises a non-periodic feature which is detectable as a capture position using the alignment subsystem.

Further advantageous embodiments of the present device manufacturing method are given in the dependent method claims. These embodiments provide advantages which correspond to the advantages mentioned above in relation to the associated apparatus claims.

According to the third aspect of the invention there is provided an alignment structure as defined in the opening paragraph above, in which the alignment structure comprises a non-periodic feature. Further advantageous embodiments are described in the associated dependent claims.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

In the present document, the terms “radiation” and “beam” are used to encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm) and extreme ultra-violet (EUV) radiation (e.g. having a wavelength in the range 5-20 nm), as well as particle beams, such as ion beams or electron beams.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

- Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;
- Figure 2 depicts an alignment subsystem of the lithographic projection apparatus;

- Figure 3 depicts a first embodiment of an alignment structure according to the present invention;
- Figure 4 depicts the alignment subsystem detection signal for two embodiments of the alignment structure of figure 3;
- Figure 5 depicts a second embodiment of an alignment structure according to the present invention, in combination with the detected phase signal of the alignment subsystem;
- Figure 6 depicts the position-dependent period change and resulting phase profile of a third embodiment of the alignment structure of the present invention;
- Figure 7 depicts schematically a fourth embodiment of the alignment subsystem of the lithographic projection apparatus according to the present invention;
- Figure 8 depicts the detected signal of the alignment subsystem of figure 7;
- Figure 9 depicts the alignment procedure for a wafer using the embodiment of figure 7; and
- Figure 10 depicts a fifth embodiment of the alignment structure according to the present invention.

Figure 1 schematically depicts a lithographic projection apparatus 1 according to a particular embodiment of the invention. The apparatus comprises:

- a radiation system Ex, IL, for supplying a projection beam PB of radiation (e.g. UV radiation). In this particular case, the radiation system also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means PM for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means PW for accurately positioning the substrate with respect to item PL; and
- a projection system ("lens") PL for imaging an irradiated portion of the mask MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example (with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

The source LA (e.g. a laser source) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

It should be noted with regard to figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and claims encompass both of these scenarios.

The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means PW (and interferometric measuring means IF), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means PM can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan

apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB; and

2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed V = Mv, in which M is the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

An alignment subsystem 21 (not shown in figure 1) is included in the apparatus for accurately measuring the position of substrate W to ensure that substrate W is properly aligned during projection. Figure 2 schematically shows the alignment subsystem 21, containing an optical subsystem with a radiation source 20, an imaging structure 24, reference structures 26, 26a, detectors 28, 28a and a processing unit 29. Although processing unit 29 is shown as one element, it will be understood that processing unit 29 may be made up of a number of interconnected processors. Radiation source 20, for example a laser, is arranged to generate a spot of light on an area 22 on substrate W. Imaging structure 24 contains a lens arrangement 240, 242 to image area 22 onto reference structure 26. Reference structure 26 has spatially periodic transmissive properties. Detector 28 is arranged to detect a spatially averaged intensity of radiation transmitted by reference structure 26. Detector 28 has an output coupled to an input of processing unit 29, which in turn has a control output coupled to second positioning means PW, which are coupled to substrate W.

Interferometric measuring means IF have an output coupled to processing

unit 29. It will be understood that various changes may be made to the alignment subsystem 21 without affecting its function. For example, mirrors may be added to be able to move elements of the alignment subsystem to more convenient locations. In one embodiment the alignment subsystem 21 is immediately next to the projection lens, but it will be understood that the alignment subsystem 21 may be further removed from the projection lens. It is not necessary that the substrate is in the path of the projection beam during alignment. In fact, another substrate, on a separate substrate table may even be in the path of the projection beam during alignment.

In operation radiation from radiation source 20 is reflected from area 22 and imaging structure 24 uses the reflected radiation to image area 22 onto reference structure 26. The imaged radiation is partially transmitted by reference structure 26 onto detector 28 which generates an electric signal that is indicative of the spatially averaged intensity of the transmitted radiation.

Processing unit 29 uses this electric signal to generate control signals for positioning means PW. This involves a number of stages (which may be executed by different elements (not shown) of processing unit 29). In a pre-positioning stage processing unit 29 moves substrate W and the alignment subsystem 21 relative to one another so that an alignment structure is imaged onto reference structure 26. In an accurate positioning stage processing unit 29 accurately measures the position of substrate W and the alignment subsystem 21 relative to one another, i.e. it determines for which output value of interferometric measuring means IF substrate W and alignment subsystem 21 are in a specific alignment relative to one another. Subsequently, processing unit 29 uses this measurement to control one or more positions with a predetermined offset to a position at which substrate W and the alignment subsystem 21 are in alignment, to which substrate is moved for illumination with projection beam PB.

For accurate alignment, substrate W contains an alignment structure 10 (see figures 3, 5, 7, 9 and 10, to be discussed below) with spatially periodic reflection properties in area 22. During accurate alignment this alignment structure 10 is imaged onto reference structure 26. The spatially averaged amount of light transmitted by reference structure 26 depends periodically on the relative phase of the image of the alignment structure 10 and reference structure 26.

Preferably, imaging structure 24 passes only selected pairs of orders of

diffraction onto reference structure 26. As shown, imaging structure 24 has been designed to filter out selected orders of diffraction from area 22. For this purpose imaging element contains lenses 240, 242 with a diffraction order filter 244 in between. A first lens 240 maps light diffracted in respective directions to respective positions on diffraction order filter 244, which transmits only light from selected positions. A second lens forms an image of area 22 from the transmitted light. Thus only selected pairs of orders of diffraction are used for imaging onto reference structure 26. Without such selective transmission position measurement is in principle also possible, but it has a worse signal to noise ratio.

Also preferably, as shown, a number of pairs of diffraction orders of the light from area 22 are treated separately. For this purpose wedges 245 are provided to ensure that different pairs of orders are imaged onto different reference structures 26, 26a, each provided with its own detector 28, 28a. Although only two reference structures 26, 26a and corresponding detectors 28, 28a have been shown, for pairs of diffraction orders +-1 and +-2 respectively, it should be understood that in practice a larger number of diffraction orders, for example seven pairs of diffraction orders +-n (n=1,2,3,4,5,6,7 ..) may be treated separately, each with its own reference structure and detector.

In an actual embodiment of the above described alignment subsystem 21, the imaging structure 24 is arranged to filter out the 0-th order, effectively halving the period (or doubling the frequency) of the alignment structure 10. A 16 μm period of the alignment structure 10 on the wafer W then effectively becomes a 8 μm period on the reference grating 26.

Although single elements 240, 242 have been shown for the sake of simplicity, it should be understood that in practice the imaging structure 24 may comprise a combination of lenses or imaging mirrors.

Furthermore, although a configuration has been shown wherein radiation is first reflected from substrate W and then transmitted through reference structure 26 before detection, it should be appreciated that other configurations may be used. For example, radiation reflected off reference structure 26 may be detected and/or radiation transmitted through substrate W may be used if substrate W permits this. Similarly, radiation may be fed to reference structure 26 first (for reflection or transmission) before being fed to

substrate W prior to detection. Also, of course, the invention is not limited to the perpendicular incidence shown in figure 2.

To allow accurate measurement of the wafer position (also called Fine Wafer Alignment, FIWA), the alignment structure or mark 10 in the area 22 on the wafer W, in accordance with the prior art, may comprise two different gratings for both the X- and Y-direction (see figure 3). By using two different grating periods for each of the marks 10 (e.g. 8.0 and 8.8 μm) and for the corresponding reference structures 26, a much more accurate positioning and a larger capture range may be accomplished (using the so called Nonius principle). Because of the periodicity of the gratings, however, there is still an inherent ambiguity in the fine positioning. In the case of the combination of the 8.0 and 8.8 μm gratings, a periodic ambiguity of +/- 44 μm exists, which can lead to one or more 88 μm errors when the initial position of the mark is outside the +/- 44 μm range. This means that the actual position of the alignment mark 10 may be at a distance of n x 88 μm from the detected position.

Coarse Wafer Alignment (COWA) followed by a FIWA may be performed in certain embodiments. Also the COWA and FIWA may be executed simultaneously. The FIWA may be performed using separate marks 10, such as the known 8.0 μm phase grating, or the known combination of a 8.0 μm and 8.8 μm phase grating using e.g. the above described technique using the Nonius principle. Alternatively, the FIWA is performed using the mark 10 according to an embodiment of the present invention (when these include at least a section with the normal period phase grating). Also, the present method and use of a phase grating as a mark 10 may be applied to check whether the right initial position has been found to perform a FIWA using a single, e.g. 8.0 μm, grating mark (confidence check).

The coarse wafer alignment may be effected using a number of different types of phase gratings for the mark 10. The underlying principle of all these types, is that a non-periodic feature of the phase grating is used to allow an exact positioning without ambiguities over a range beyond the ambiguity range of the fine wafer alignment method. Thereby, the capture range and/or the robustness of a periodic alignment system (e.g. using 8.0 μm gratings or a combination of 8.0 μm and 8.8 μm gratings) are enlarged beyond the

periodicity of that periodic alignment system (8.0 μm and 88 μm, resp.).

The non-periodic feature may be included in the phase grating mark 10 on the wafer in a number of manners. A number of embodiments of the marks according to the present invention will be discussed below, together with possible specific processing required for that embodiment. In general, two classes of marks 10 which embody the present invention exist, i.e. a first class in which the phase of a detected signal is used to determine the mark position (or better: non-periodic feature position), and a second class in which the amplitude of a detected signal is used to determine the mark position.

As a first type of mark 10, a so called Phase Jump Mark is shown in figure 3. In broken lines, the reference grating 26 (e.g. with a periodicity of 8.0 μm) is shown, which is moved relative to the phase jump mark 10 shown in non-broken lines. Such a phase grating mark 10 comprises lines and spaces as conventional alignment marks (e.g. spaced at 8.0 μm), but the periodicity of the grating is broken at one or more positions 15 of the mark, resulting in a phase jump of the mark at this position(s). It can also be defined that the phase jump mark 10 comprises two parts 11, 12 with a phase grating having the same periodicity of lines and spaces, and a feature region 15, where the space between the two parts 11, 12 is different. In a 8.0 μm phase grating, e.g. one of the spaces 15 may be reduced to 4 μm, 4/7 μm, 200 nm or enlarged to 12 μm (as shown in figure 3). With the 4 μm and 12 μm spaces, the two parts 11, 12 of the phase grating will be exactly in opposite phase to each other.

Because of the non-periodic feature 15 in the periodic grating, a phase change will occur when the reference grating 26 is moved with respect to the phase grating 10 on the wafer W using the alignment subsystem 21 discussed above. This phase change is present in each of the detected orders n of the reflected light beam. The signal received on one or more of the detectors 28, 28a may be processed to derive the phase of the received signal, e.g. by applying a best fit on the measured and processed signal phases in a predetermined position window. At the point in the scanning direction (e.g. the x-direction) where the alignment signal phase changes at maximum speed, the captured alignment mark position 15 is present.

Tests have been performed using a number of different phase changes (4μm,

4/7μm, 12 μm and 200 nm), and the captured alignment mark 15 has been detected using different orders of the diffraction grating. It has been found that the 4 μm phase jump mark provides the best results with the lowest order measurements (best reproducibility of results).

However, it has also been found that using the phase jump marks 10 with a rather large spacing (4 μm) the detected signal at the actual alignment position is actually the weakest signal over a larger position window. This of course may result in unreliable results. It has been found that the weak signal is the result of the left and right part of the phase jump mark 10 with a 4 μm spacing being out of phase. When the spacing is made much smaller (in the order of 100 nm, e.g. 200 nm) this signal weakening effect is much less prominent or even absent, and still the spacing 15 is large enough to be detected using the phase detection method. In figure 4, this effect is illustrated: figure 4a shows the alignment signal S as a function of the displacement x from the alignment subsystem 21 for the phase jump mark having a 4 μm spacing, and figure 4b shows the alignment signal S as a function of the displacement x from the alignment subsystem 21 for the phase jump mark having a 200 nm spacing. It can be seen, that the alignment signal S for the 200 nm spacing phase jump mark 10 has a much larger signal strength than the alignments signal S for the 4 μm spacing phase jump mark 10.

The non-periodic feature of the mark 10 can also be embodied as a linear phase profile mark (LPPM). This embodiment is shown in figure 5. In this embodiment, two parts 11, 12 of the phase grating 10 both have a period (slightly) different from the reference grating 26. When moving the reference grating 26 with respect to the LPPM 10, two linearly varying phase profile signals can be detected.

For one of the LPPM parts 11, 12 (taking the reference grating period of 8.0 μm), the alignment signal then looks like

$$S(x) = dc + A\cos\left[\frac{2\pi}{(8+\Delta)}x\right]$$
$$= dc + A\cos\left[\frac{2\pi}{8}\left(x - \frac{\Delta}{8}x\right)\right] \qquad (\Delta << 8)$$

It can be seen that the aligned position varies (Δ/8) micron per micron shift of the expected position. To have a non-periodic feature allowing to detect a unique position, the gratings 11, 12 of the LPPM 10 are constructed such that the detected alignment phase signal Δx_{ap} shows two slopes with opposite slope sign (See figure 5 bottom part). The unique alignment position can than be derived from the intersection of the two slopes.

In this embodiment, it should be kept in mind that the different periods of the LPPM 10 will lead to different diffraction angles, which must still be transmitted by the diffraction order filter 244 (see figure 2). The order positions are related to the mark period by

$$x_{ord} = n_{ord} \frac{\lambda \cdot f}{d_0}$$

where f is the focal distance and d_0 is the mark period. A change in the period of 8 nm will lead to a phase slope of 1 nm/μm which can be accurately measured. A relative period change of 1‰ will lead to a shift of the diffraction order of ~ 3μm.

The two slopes may be measured using a single reference grating 26 and a single illumination spot, or, as depicted in figure 5, using two reference gratings 26 and two illumination spots to allow simultaneous determination of the two sloped signals.

In an even further embodiment of the first class of phase gratings 10, the variation of the grating period has a sinusoidal profile (Sinusoidal Phase Profile Mark, SPPM). The two slopes in the resulting measured signal are then replaced by a sinusoidal shape, of which the top can easily be detected. When the period of the sinusoidal phase profile is much larger than the period of the reference grating (e.g. > 8 μm, preferably even > 88 μm), a sinus fitting of the detected phase signal profile would provide the capture position 15 of the alignment mark 10. Such a sinusoidal phase profile can be obtained from a position-dependent period change:

$$\Delta(x) = \frac{\cos\left(\frac{2\pi}{L}x\right) - 1}{x} \qquad \Rightarrow \qquad phase\ profile = \cos\left(\frac{2\pi}{L}x\right) - 1$$

where again we have the boundary condition that $\Delta(x) << 8\mu m$. In this equation, Δ(x) is the position-dependent period change, x is the distance along the (longitudinal) x-direction, and L is the alignment mark 10 length. An example of the

sinusoidal phase profile (solid line), and the associated required position dependent period change Δ(x) (broken line) for the SPPM 10 is shown in figure 6.

The second class of marks 10 uses the intensity of the detected alignment signal to provide the capture position of the non-periodic feature 15 of the mark 10.

In a first embodiment of the second class of marks 10, use is made of the finite properties of regularly used marks, such as a versatile scribeline primary mark (VSPM), a regular 8.0 μm phase grating mark or a combination of a 8.0 μm and 8.8 μm phase mark. In an exemplary embodiment, the marks present are scanned under an angle α to the longitudinal direction of the mark 10. The angle α may vary between 0° and 90°, in which α=0° and α=90° are special cases. In figure 7, an exemplary arrangement of the scanning with the illumination spot and an existing phase grating mark 10 comprising two separate phase gratings 31, 32 is shown. In this case, both phase gratings 31, 32 present (e.g. an 8.0 μm and a 8.8 μm phase grating) are scanned by the illumination spot 30 with the same (but opposite signed) scanning angle α. In figure 7, also a coordinate axis is shown, indicating that the phase gratings 31 and 32 have their longest dimension in the x-direction and a smaller dimension in the y-axis.

The intensity signal detected by the alignment subsystem 21 for a single scan (e.g. left part in figure 7, detecting the 8.0 μm grating 31) is shown in the plot of figure 8 as a function of the y-position. In figure 8, also the envelope of the detected signal is shown by the broken line, which allows to determine the capture position. The detected capture position in this case, however, is the capture position in the direction (y-direction) perpendicular to the longitudinal direction (x-direction) of the phase grating 31. When both phase gratings 31, 32 are used as shown in figure 7, a more robust result of the capture position will result.

The diagonal scan method as discussed with reference to the embodiment shown in figure 7, may also be executed using only a single grating 31.

The envelope of the intensity signal obtained from a phase grating 31, 32 extending in the x-direction provides the capture position of the phase mark 10 in the y-direction. In a similar manner, the capture position of a phase mark 10 extending in the y-direction will provide a capture position in the x-direction. When phase marks 10 are

present on the wafer in both the x- and y-direction in a known configuration (i.e. with known mutual offsets 35, 36, see the example shown in figure 9 with two phase gratings 31, 32 extending in the x-direction and two phase gratings 33, 34 extending in the y-direction), the found capture positions in the x- and y-direction can be used as expected positions in a normal coarse alignment procedure (e.g. using a combination of 8.0 μm and 8.8 μm phase gratings as described above). Sometimes, it is still necessary to perform a coarse alignment, as the accuracy of the diagonal scan procedure (the envelope signal) is e.g. 30 μm dependent on the width of the phase grating marks 10 used, is sufficient to determine the right top in a 88 μm periodic signal (as delivered by the 8.0/8.8 μm phase grating combination discussed above), but not sufficiently accurate to determine the right top in a 8.0 μm periodic signal.

This diagonal scan method prevents making a periodic error, as during a scan of a phase grating 31..34, there will only be one distinct envelope shape present in the detected signal. When no signal (or a signal below a predetermined threshold) is received at all using the alignment subsystem 21, this indicates that the phase grating mark 10 has been missed. Then, the search window of the alignment subsystem 21 should be extended or shifted (e.g. with a positional shift equal to the (known) length of the phase grating 31…34. The diagonal scan method is particularly suited to check whether the detected position of the wafer alignment using a detection method having possible periodic errors, is correct (confidence check).

For α=0°, the non-periodic feature 15 of the mark 10 is the start and end of the phase grating 31…34 in the longitudinal direction of the phase grating 31…34. The capture position (either the first edge or the second edge of the phase grating 31…34, or a combination thereof) may be derived from the envelope of the detected alignment signal, the length of which should correspond to the length of the phase grating 31…34.

For α=90°, the non-periodic feature of the phase grating is the start and end of the phase grating 31…34 in the cross direction (i.e. perpendicular to the longitudinal direction). In this case, a capture position in one direction (e.g. y-direction) may be determined using the x-direction phase grating 31, 32. In this case, when the reference grating 26 and the phase grating mark 10 happen to be perfectly aligned, it is possible that

no signal is detected at all using the alignment subsystem 21. However, a new scan with a very small change in the longitudinal direction of the phase grating mark 10 will then provide sufficient signal to determine the capture position in the y-direction. This special case of the diagonal scan has a further disadvantage compared to the diagonal scan with an angle $0° \leq \alpha < 90°$. For the case of α=90°, the alignment subsystem will only detect the envelope signal and will not detect an alignment signal in which also the periodic features of the phase grating 31...34 are present (which would allow the signal also to be used for further (fine) wafer alignment).

The diagonal scan method of the alignment subsystem provides a number of further advantages, which are predominantly present for the cases in which $0° < \alpha < 90°$. The scan doesn't necessarily use more time, as the signal acquisition for capturing and aligning can be performed simultaneously. Also, no further hardware needs to be added to the alignment subsystem 21, as the illuminating beam (spot 30) and associated drive means, and the detectors 28 and associated processing elements 29 are already present. As the diagonal scan uses the same marks 10 on the wafer W as used for the fine wafer alignment, no further space is needed on the wafer W, which allows a higher yield per wafer. The robustness of the diagonal scan method is the same as for the existing fine wafer alignment: when a phase grating mark 10 can be detected using the normal (x-direction) scanning of a phase grating mark 10, the phase grating mark 10 will also be detected using the diagonal scanning method. In present systems, the choice of the size of the illuminating beam is a trade off: for optimal performance it should be very small to prevent cross talk with other features on the wafer W. However, a very small illuminating beam will enlarge the chance of missing the phase grating mark 10 at all. Using the diagonal scan however, the chance of actually hitting the phase grating mark 10 (which is much longer than wide) is greatly enhanced, allowing to actually use a small illuminating beam.

In a further embodiment of the present phase grating mark of the second class (intensity detection), the mark comprises a first part with a periodicity of, in general, X μm (e.g. X= 8.0 μm), and an adjacent second part with a periodicity of X/n, n being an integer number (e.g. n =7). This embodiment is shown schematically in figure 10 in which

the mark 10 comprises a first part 11 with a periodicity of 8 μm and a second part 12 with a periodicity of 8/7 μm. When detecting the n-th order diffraction of this mark 10, signals with the same periodicity will be detected over the entire mark 10, but there will be a noticeable change in intensity at the changeover 15 from X to X/n periodicity. This allows the detection of the capture position 15 of the mark 10. For a robust and effective error free detection of the capture position 15, the change in signal from the alignment subsystem 21 should be as clear as possible, but still, a signal must be detected from both parts 11, 12 of the mark 10. In practice, this means that e.g. a combination of a 8 μm and 8/7 μm (or 8/5 μm) phase grating will provide a workable mark 10 for coarse wafer alignment.

In an alternative version, not the periodicity is changed over the mark 10, but the duty cycle of the spaces and lines is changed at one or more positions in the phase grating 10. Duty cycle is the ratio of the width of a line and a space in the alignment structure. Under normal circumstances, phase gratings 10 are provided with lines and spaces of equal dimension (duty cycle 50%). When the duty cycle of the lines and spaces is changed, this will be noticeable in the amplitude of the signal from the alignment subsystem 21, and indicates the capture position 15 of this embodiment of the mark 10.

Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

CLAIMS

1. A lithographic projection apparatus comprising:

- a radiation system (Ex, IL) for providing a projection beam of radiation;
- a support structure (MT) for supporting patterning means (MA), the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table (WT) for holding a substrate (W) with an alignment structure (10) thereon, the alignment structure (10) having spatially periodic optical properties;
- a projection system (PL) for projecting the patterned beam onto a target portion of the substrate (W); and
- an alignment subsystem (21) for aligning the substrate (W) on the substrate table (WT) relative to the patterning means (MA), the alignment subsystem (21) comprising
  - an optical interference arrangement (20, 24, 26) for optically processing light reflected from or transmitted by the alignment structure (10), to produce measurement light whose intensity varies with a phase of the spatially periodic alignment structure (10) relative to a reference position defined relative to the patterning means (MA);
  - a sensor (connected to the optical interference arrangement for measuring intensity and/or phase information of the measurement light,
  - an actuator (PW) for controlling a relative position of the substrate table (WT) and the patterning means (MA) based on the intensity and/or phase information of the measurement light,

characterized in that

the alignment structure (10) comprises a non-periodic feature (15) which is detectable as a capture position or a check position using the alignment subsystem (21).

2. Lithographic projection apparatus according to claim 1, in which the non-periodic feature (15) induces a phase shift in the detected phase information of the measurement light.

3. Lithographic projection apparatus according to claim 2, in which

the non-periodic feature (15) is formed by a phase shift between two parts (11, 12) of the alignment structure (10) by a change of the width of one of the lines or spaces of the alignment structure (10).

4. Lithographic projection apparatus according to claim 2, in which the optical interference arrangement comprises a reference grating (26), the non-periodic feature (15) comprises a transition from a first part (11) to a second part (12) of the alignment structure (10) with a first and second periodicity, respectively, which first and second periodicity are below, respectively above the periodicity of the reference grating, and the alignment subsystem (21) is arranged to detect the capture position or check position from the resulting sloped phase information of the measurement light.

5. Lithographic projection apparatus according to claim 2, in which the alignment structure (10) comprises a position dependent period change according to

$$\Delta(x) = \frac{\cos\left(\frac{2\pi}{L}x\right) - 1}{x}$$

in which Δ(x) is the position dependent period change, x is the position along the alignment structure and L is the length of the alignment structure (10) over which the phase should vary, and the alignment subsystem (21) is arranged to detect the capture position or check position from the resulting sinusoidal shaped phase information of the measurement light.

6. Lithographic projection apparatus according to claim 1, in which the non-periodic feature (15) induces a spatially dependence of the intensity in the detected intensity information of the measurement light.

7. Lithographic projection apparatus according to claim 6, in which the non-periodic feature (15) comprises the finite dimension of the alignment structure (10), and the alignment subsystem (21) is arranged to detect the capture position or check position from the envelope of the intensity of the measurement light.

8. Lithographic projection apparatus according to claim 7, in which the alignment structure (10) has a first dimension in a first direction and a second dimension in a second direction, in which the second direction is substantially perpendicular to the first direction, in which the non-periodic feature (15) is the first and/or second dimension of the alignment structure (10).

9. Lithographic projection apparatus according to claim 6, in which the non-periodic feature (15) is formed by the transition from a first part (11) of the alignment structure (10) to a second part (12) of the alignment structure (10), the first part (11) having a periodicity of X μm and the second part (12) having a periodicity of X/n μm, n being an integer number, and the alignment subsystem (21) is arranged to detect the capture position or check position from a change in the intensity of an n-th order of diffraction of the measurement light.

10. Lithographic projection apparatus according to claim 6, in which the non-periodic feature (15) is formed by the transition from a first part (11) of the alignment structure (10) to a second part (12) of the alignment structure (10), the first part (11) having a first duty cycle value of the lines and spaces and the second part (12) having a second duty cycle value of the lines and spaces, and the alignment subsystem (21) is arranged to detect the capture position or check position from a change in the intensity of the measurement light.

11. A device manufacturing method comprising the steps of:

- providing a substrate (W) that is at least partially covered by a layer of radiation-sensitive material, the substrate (W) comprising an alignment structure (10) with spatially varying optical properties;
- providing a projection beam of radiation using a radiation system (Ex, IL);
- using patterning means (MA) to endow the projection beam with a pattern in its cross-section;

- aligning the substrate (W) relative to the patterning means (MA), said aligning comprising:

-incorporating the substrate (W) in an optical interference arrangement (20, 24, 26), which optically processes light reflected from or transmitted by the alignment structure (10), to produce measurement light of which the intensity varies with a phase of the spatially periodic alignment structure (10) relative to a reference position defined relative to the patterning means (MA);

- measuring intensity and/or phase information of the measurement light;

- controlling a relative position of the substrate (W) and the patterning means (MA) based on the intensity and/or phase information; and

- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material, characterized in that

the substrate (W) is aligned relative to the positioning means (MA) using the alignment structure (10) comprising a non-periodic feature which is detectable as a capture position or check position.

12. Device manufacturing method according to claim 11, in which the non-periodic feature (15) induces a phase shift in the detected phase information of the measurement light.

13. Device manufacturing method according to claim 12, in which the non-periodic feature (15) is formed by a phase shift between two parts (11, 12) of the alignment structure (10) by a change of the width of one of the lines or spaces of the alignment structure (10).

14. Device manufacturing method according to claim 12, in which the optical interference arrangement comprises a reference grating (26), the non-periodic feature (15) comprises a transition from a first part (11) to a second part (12) of the alignment structure (10) with a first and second periodicity, respectively, which first and second periodicity are below, respectively above the periodicity of the reference grating,

and in which the capture position or check position is detected from the resulting sloped phase information of the measurement light.

15. Device manufacturing method according to claim 12, in which the alignment structure (10) comprises a position dependent period change according to

$$\Delta(x) = \frac{\cos\left(\frac{2\pi}{L}x\right) - 1}{x}$$

in which Δ(x) is the position dependent period change, x is the position along the alignment structure and L is the length of the alignment structure (10) over which the phase should vary, and the capture position or check position is detected from the resulting sinusoidal shaped phase information of the measurement light.

16. Device manufacturing method according to claim 11, in which the non-periodic feature (15) induces a spatially dependence of the intensity in the detected intensity information of the measurement light.

17. Device manufacturing method according to claim 16, in which the non-periodic feature (15) comprises the finite dimension of the alignment structure (10), and the capture position or check position is detected from the envelope of the intensity of the measurement light.

18. Device manufacturing method according to claim 17, in which the alignment structure (10) has a first dimension in a first direction and a second dimension in a second direction, in which the second direction is substantially perpendicular to the first direction, and the non-periodic feature (15) is the first and/or second dimension of the alignment structure (10).

19. Device manufacturing method according to claim 16, in which the non-periodic feature (15) is formed by the transition from a first part (11) of the alignment structure (10) to a second part (12) of the alignment structure (10), the first part (11) having

a periodicity of X μm and the second part (12) having a periodicity of X/n μm, n being an integer number, and the capture position or check position is detected from a change in the intensity of an n-th order of diffraction of the measurement light.

20. Device manufacturing method according to claim 16, in which the non-periodic feature (15) is formed by the transition from a first part (11) of the alignment structure (10) to a second part (12) of the alignment structure (10), the first part (11) having a first duty cycle value of the lines and spaces and the second part (12) having a second duty cycle value of the lines and spaces, and the capture position or check position is detected from a change in the intensity of the measurement light.

21. Alignment structure for aligning a work piece relative to a reference position using interferometric measurements, the alignment structure (10) comprising at least one phase grating mark having a plurality of adjacent lines and spaces with a predetermined periodicity, characterised in that the alignment structure (10) comprises a non-periodic feature (15).

22. Alignment structure according to claim 21, in which the non-periodic feature (15) is formed by a phase shift between two parts (11, 12) of the alignment structure (10) by a change of the width of one of the lines or spaces of the alignment structure (10).

23. Alignment structure according to claim 21, in which the non-periodic feature (15) comprises a transition from a first part (11) to a second part (12) of the alignment structure (10) with a first and second periodicity, respectively, which first and second periodicity are below, respectively above the periodicity of a reference grating.

24. Alignment structure according to claim 21, in which the alignment structure (10) comprises a position dependent period change according to

$$\Delta(x) = \frac{\cos\left(\frac{2\pi}{L}x\right) - 1}{x}$$

in which $\Delta(x)$ is the position dependent period change, x is the position along the alignment structure and L is the length of the alignment structure (10) over which the phase should vary.

25. Alignment structure according to claim 21, in which the non-periodic feature (15) is formed by the transition from a first part (11) of the alignment structure (10) to a second part (12) of the alignment structure (10), the first part (11) having a periodicity of X μm and the second part (12) having a periodicity of X/n μm, n being an integer number.

26. Alignment structure according to claim 21, in which the non-periodic feature (15) is formed by the transition from a first part (11) of the alignment structure (10) to a second part (12) of the alignment structure (10), the first part (11) having a first duty cycle value of the lines and spaces and the second part (12) having a second duty cycle value of the lines and spaces.

27. Substrate for preparation of a work piece, in which the substrate (W) is provided with an alignment structure (10) according to one of the claims 21 to 26.

P-0426.000-EP

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14. 02. 2003

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ABSTRACT

Lithographic apparatus with alignment subsystem, device manufacturing method using alignment, and alignment structure

A lithographic projection apparatus comprising an alignment subsystem (21) for aligning the substrate (W) on the substrate table (WT) relative to the patterning means (MA). The alignment structure (10) comprises a non-periodic feature (15) which is detectable as a capture position or a check position using a reference grating (26) in the alignment subsystem (21). The non-periodic feature (15) may cause a phase effect in the detected signal of the alignment subsystem (21) or an amplitude effect.

[Fig. 3]

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Fig 1

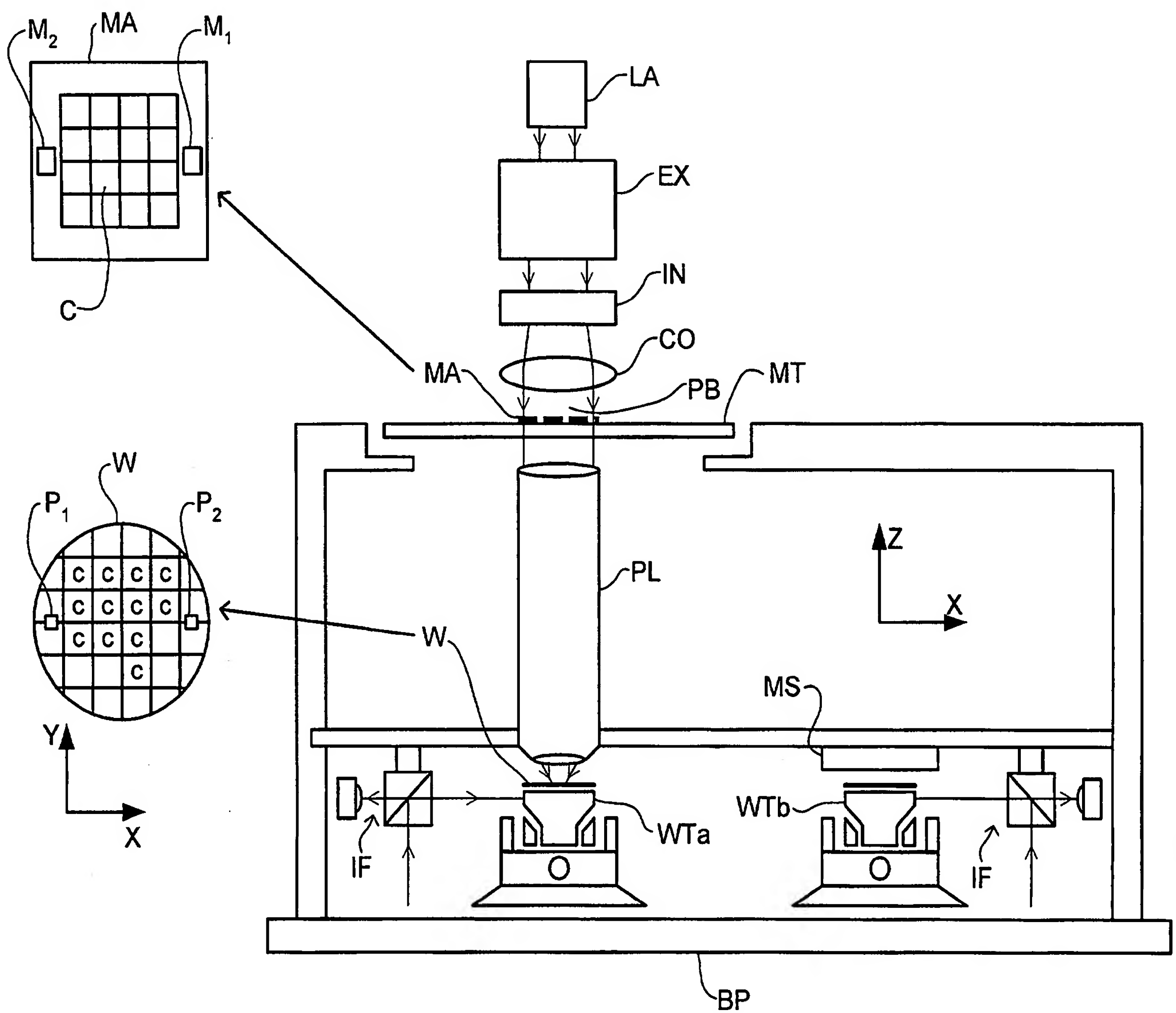

Fig 2

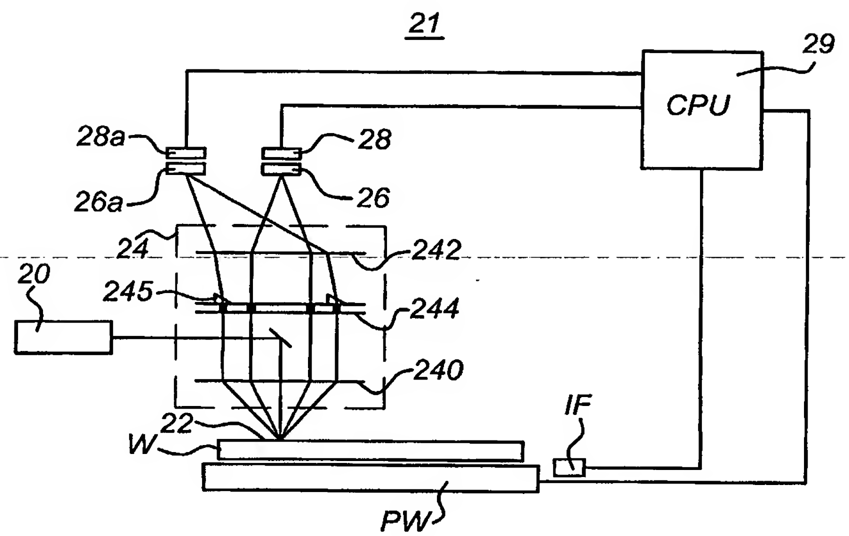
21
29
CPU
28a
28
26a
26
24
242
20
245
244
240
IF
22
W
PW

Fig 3

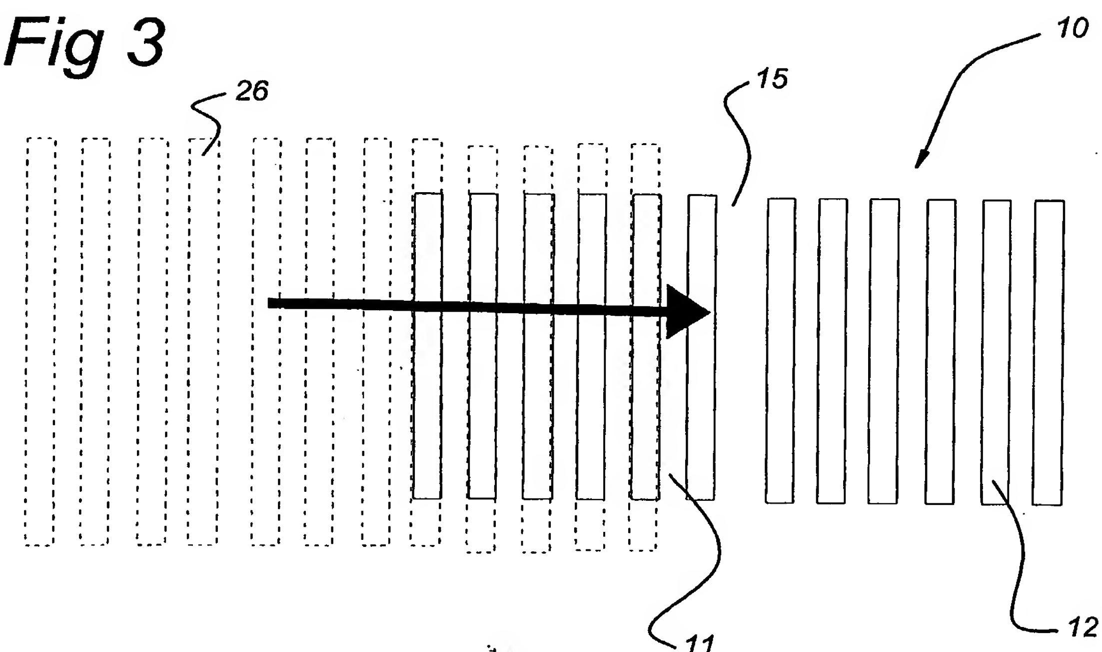
10
26
15
11
12

Fig 4a

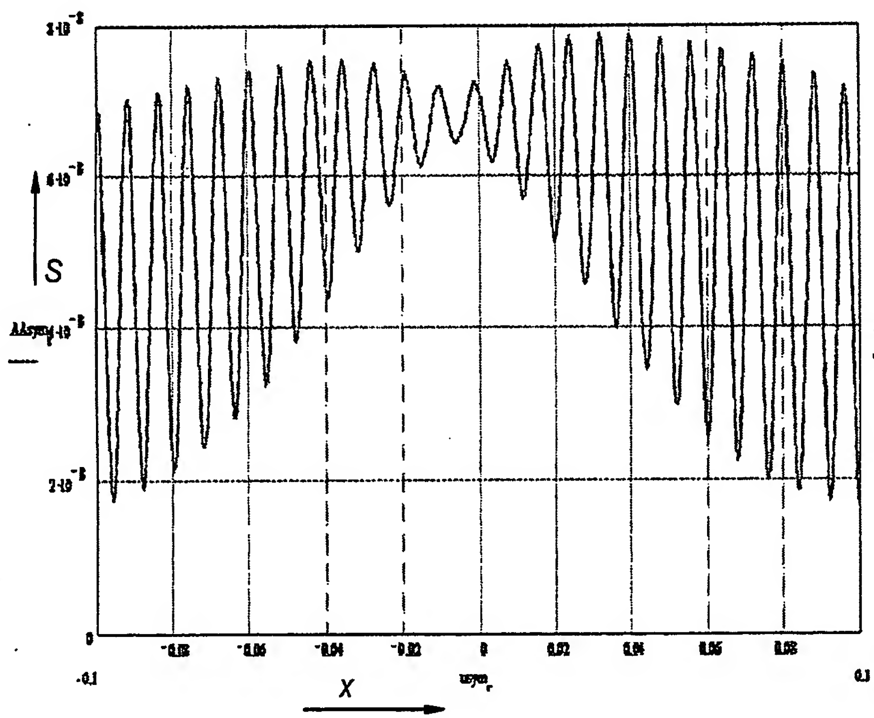

Fig 4b

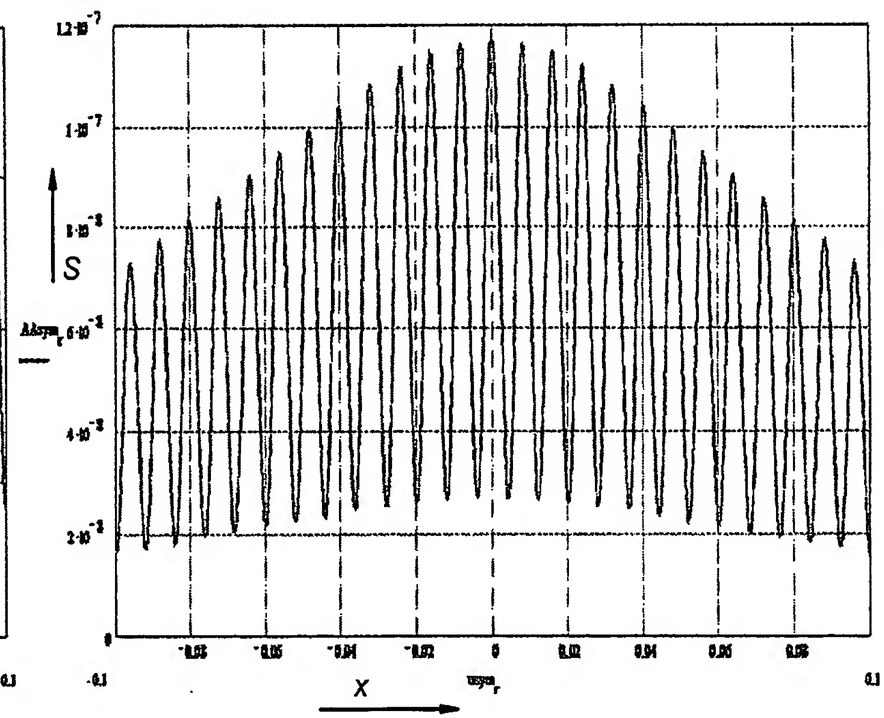

Fig 5

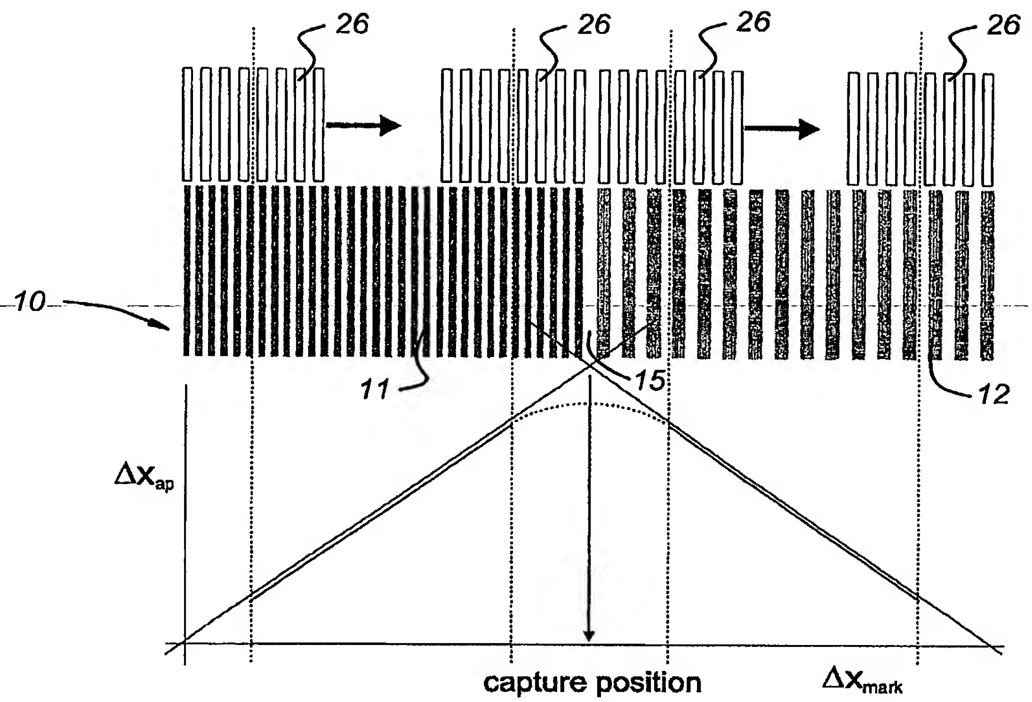
26
26
26
26
10
11
15
12
Δx_{ap}
capture position
Δx_{mark}

Fig 6

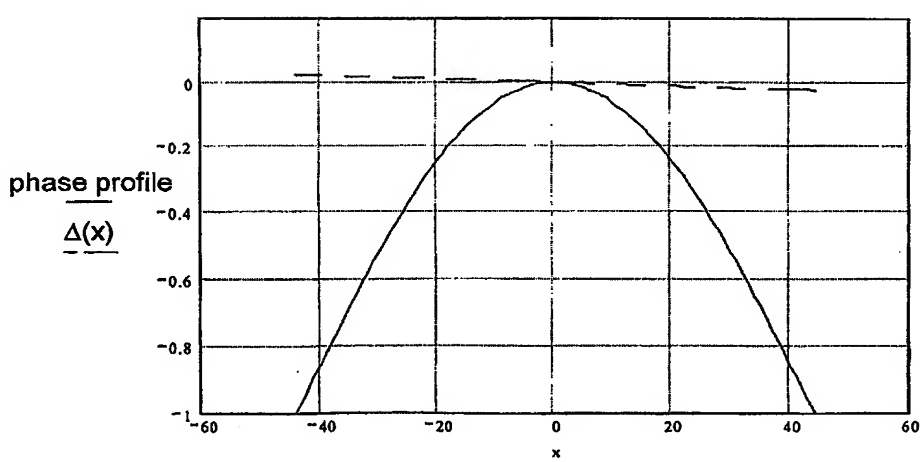
phase profile
$\Delta(x)$
0
-0.2
-0.4
-0.6
-0.8
-1
-60
-40
-20
0
20
40
60
x

Fig 7

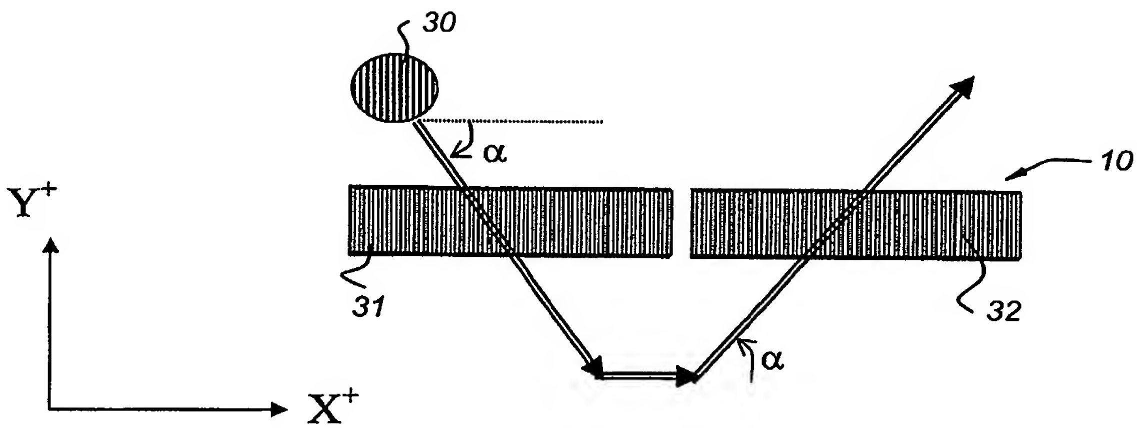

Fig 8

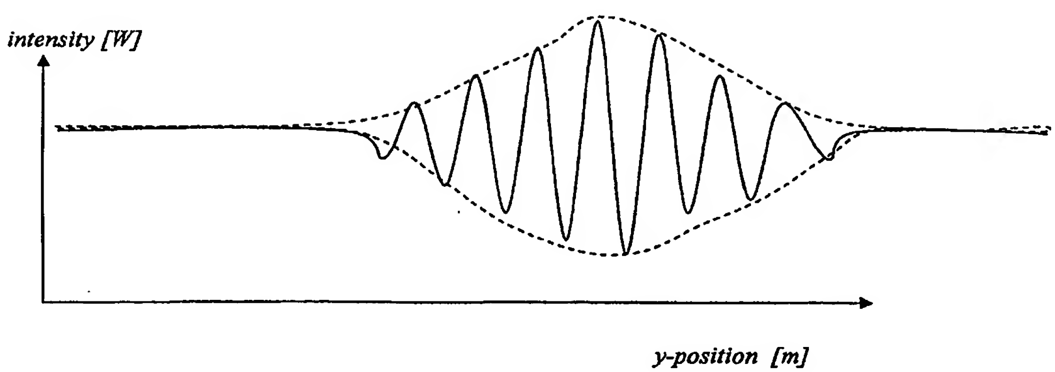

Fig 9

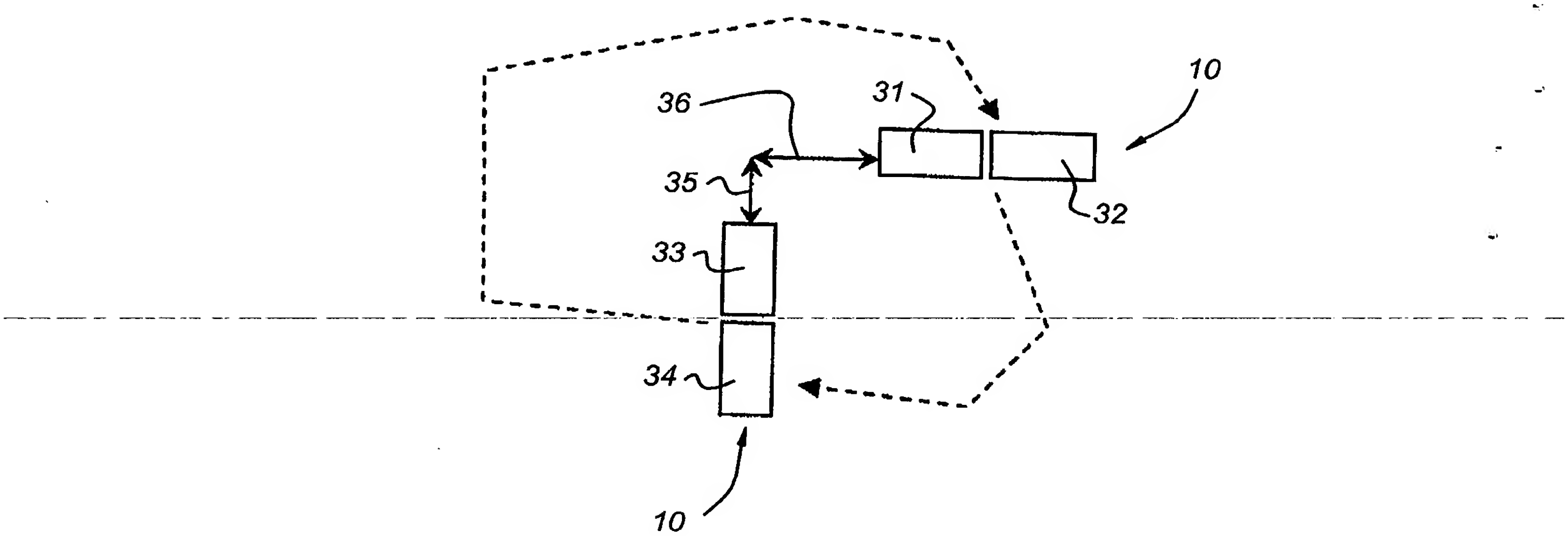

Fig 10